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CONCEPTS OF ENGINEERING BIOTECHNOLOGY IN OCCUPATIONAL HEALTH

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CONCEPTS OF ENGINEERING BIOTECHNOLOGY IN OCCUPATIONAL HEALTH

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I. Introduction

A need has become increasingly apparent for focusing the attention of engineers upon the fundamentals of engineering in relation to the control of occupational health hazards. This paper is intended as an appraisal of the problem and to serve as an introduction to the basic principles involved. It is intended not only for those concerned with the specialized aspects of sanitary and industrial hygiene engineering, but for all engineers.

The importance of adverse factors in the working environment as sources of ill health was recognized as early as the Fourth Century, B. C., when Hypocrates first described lead poisoning. Recognition of the occupational origin of certain diseases was noted throughout the following years. However, during this period in which medicine was developing the philosophy of therapy of the individual as an entity, and engineering was undergoing the evolution of the technology which was to lead to the production of our large modern centers of population, primary attention insofar as disease preventive measures was concerned was focused upon those conditions relating to the biological origin of infection. The early concern of physicians with problems of occupational health is evidenced by the fact that in 1700 the first complete publication on occupational diseases was published by Ramazzini. The necessity for the inclusion of engineers and scientists in the public health team was recognized as early as 1850 in the Shattuck Report.[1] Although this report pointed out that the engineer member of the board should possess competence in determination of planning and construction of public works in the best "architectural sanitary arrangements of public buildings, workshops, etc.," it was not until 1869 that the Massachusetts State Board of Health included an engineer, and 36 years later in 1886 before its organization included an engineering division, according to Baity.[2]

The latter part of the 19th century and the early part of the 20th, with increasing understanding of the role of bacteria in the transmission of disease, saw the development to a high degree of the classic features of sanitary engineering, such as purification of water, sewage disposal, collection and disposal of waste, and control of insect and rodent vectors of disease. There was little, if any, requirement that engineers have an intimate understanding of the physiological mechanisms involved except as a matter of transitory interest. It is doubtful that more than a handful of individuals realized the full importance of engineering in the control of exposure of personnel to hazards

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to their health as part of their work environment. The development of industrial hygiene engineering is of fairly recent origin. It was not until 1913 that New York State included a mechanical engineer and chemist on the staff of the "Medical Inspector of Factories." This was probably the first such use of engineering skills in an organized industrial health program.

The responsibilities of engineers with regard to the effects of the projects conceived and directed by them upon the community at large and the individuals who utilize them have been recognized for many years. The code of practice of the American Society of Civil Engineers, adopted January 18, 1927, states as follows:

> "Part 5. Relations With the Public.
>
> * * * * *
>
> "(5) He shall give consideration to the effect upon the community of every proposed project with which he is connected.
>
> * * * *
>
> "(8) In addition to the safeguards required of him, engineers shall recognize their broad obligation to provide amply for the safety, health and comfort of the public insofar as affected by their operations."

The concern of engineers with responsibility for the safeguarding of life and health is given legal status in the laws of the various states. The practice of engineering as defined in the Model Law recommended by the Engineers Council for Professional Development and the National Society of Professional Engineers and which has been adopted by all 48 states is, "responsible professional service which may include consultation, investigation, evaluation, planning, designing, or supervision of construction in connection with any public or private utility such as structures, machines, equipment, processes, works or projects wherein the public welfare or the safeguarding of life, health and property is concerned or involved when such professional service requires the application of engineering principles and the interpretation of engineering data."[4] The Canon of Ethics for Engineers, adopted by the Engineers' Council for Professional Development in October, 1947, reiterated this philosophy in the following statement:

> "He will have due regard for the safety of life and health of the public and employees who may be affected by the work for which he is responsible."

Unfortunately, all too few engineers have been aware of the specialized nature of this problem. In order to achieve these necessary ends of concern with safety and health protection, it is apparent that more than knowledge of the basic physical sciences is involved. The Shattuck Report is frequently cited as the origin of an integrated approach to public health. All too frequently, however, the implication that physicians and other professions have an interest in preventive measures is not broadened to include the requirement that engineers must have an understanding of medical sciences to accomplish this end. One of the basic approaches in industrial hygiene and occupational health is the fundamental concept that workers' responses to stresses can be expressed in the form of finite relationships. This makes it possible to recognize and predict the effects of working conditions. On this basis standards of human performance may be formulated from which industrial design and operation procedures can be developed to eliminate or minimize harmful effects and

promote the health and well-being of workers.[5] A requirement is thus created for engineers to have a basic knowledge of physiology and anatomy. It is essential that a greater awareness be had by all engineers of the effects of the works they conceive upon man, the user thereof. As our technology becomes increasingly complex, the sanitary and industrial hygiene engineer's role becomes of even greater importance in the protection of the health of the community and working population. All engineers, regardless of specialty, need to understand more about "human engineering" if they are to recognize their obligation for health comfort and safety.

II. Biotechnology and the Engineer

According to Hatch, sanitary engineering is concerned with the control of the human environment to the end that environmental stresses upon man are maintained within acceptable limits in respect to health and well-being.[6] This definition implies more than mere correction of deficiencies after they have occurred. Furthermore, it recognizes the concept pointed out above that environmental stresses can be defined and specified and that based upon this specification, alterations to the environment may be designed. Criticism has been frequently leveled at engineers that they tend to limit their activities and responsibilities to those areas which can be solved only by the laws of physical science. As a result of a lack of training in the principles and fundamentals of physiology and psychology, only functional requirements and economics of production are generally considered.[5]

The industrial potential of the United States has increased 700% since 1900. Over one-half of this increase has occurred in the last ten years.[7] Concurrent with this expansion of industrial potential, there has been a tremendous increase in exposures to hazardous or potentially hazardous conditions in every walk and mode of life. It is estimated that approximately 60 million persons in the United States are employed in various occupations.[8] The chemical industry has been phenomenal growth and now has the capability of synthesizing new chemicals for specific purposes. An example of this is the development of synthetic insecticides. In 1945 there were only a few insecticides in widespread use, and their toxicity was well understood. Today, there is a host of materials which are potentially dangerous to human beings in widespread use.[8] The shelves of the average American home contain chemicals which afford serious dangers to health and well-being unless used intelligently.

It is obvious that in order to successfully cope with the problems created by the complexity of the modern environment (both living and working, be it in a large industrial plant, small workshop, or in a self-employed operation) integrated efforts on the part of a wide variety of disciplines are required. The engineer must understand the physiological processes involved as a result of exposure to chemicals and other hazards in the environment if he is to assess the stresses created by the environment and translate them into appropriate designs and controls. A fundamental knowledge of physiology, phychology, anatomy, and the biological sciences is required if the engineer is to adequately accomplish his mission.[9] Adequate and economical environmental control measures for protection against hazards must be predicated upon a knowledge of the mechanisms by which compounds are absorbed into the body, what effects are produced following absorption, how they may be detoxified, where they are stored, and how they are eliminated. Both the long range and the immediate effects of exposure to a wide variety of abnormalities of environmental conditions should be a fundamental consideration in the design of any structure or process.

As pointed out by Hatch, human engineering is engineering design in relation to man's anatomical, physiological capabilities and limitations. He further points out the excellent opportunities for engineers to actively function in the field of physiology and cites such contributions as the work in thermal physiology of the American Society of Heating and Ventilating Engineers. As long as the performance limits of man exceeded those of his machines or work environment, such considerations as are inherent in engineering application within the definition of "human engineering" were probably of only minor significance. As machines exceed man's capability in their performance, these considerations become of paramount importance. In the aviation industry in particular, this has become a matter of serious concern.[11] When properly applied, this knowledge of the capabilities and limitations of man in conjunction with basic engineering knowledge can be utilized to determine the adequacy of the environment, man's ability to function within the environment or to synthesize solutions to the problem of his existence therein.

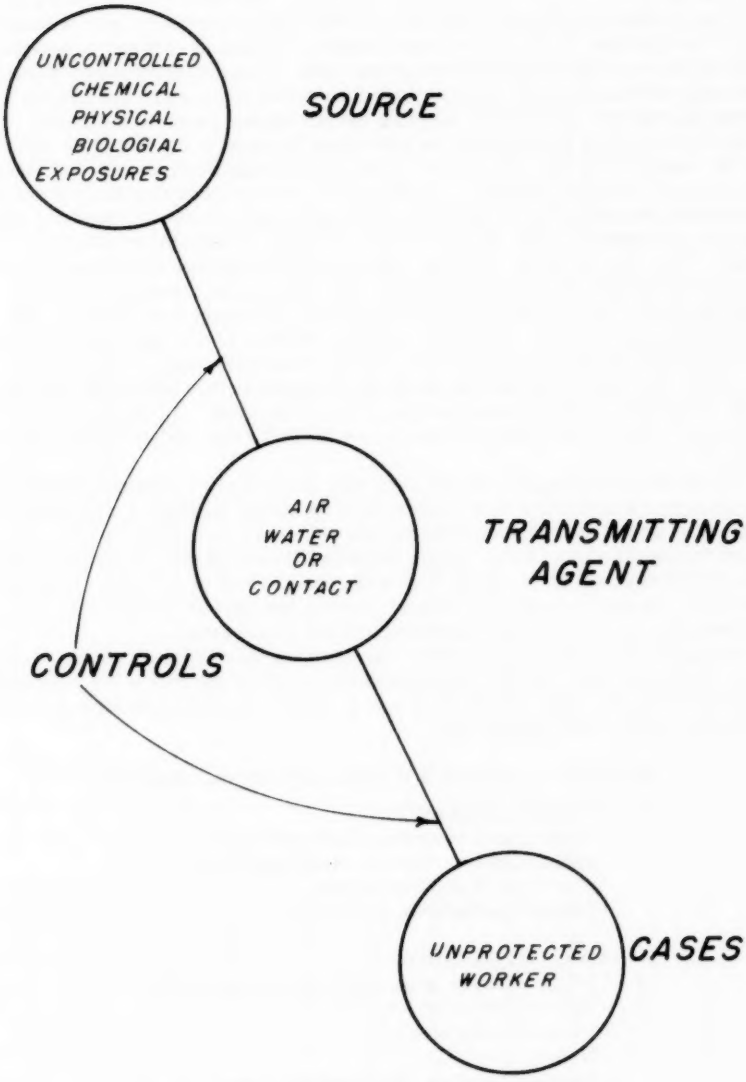
III. Fundamental Concepts of Occupational Health

The function of any program of occupational health is to increase and maintain maximum productive effectiveness of the work population. Productive effectiveness in a sense is a measure of individual productive ability. There is a definite inter-relationship between general community health and the health of the working population. The engineer must concern himself not only with means of preventing disease and controlling hazards, but also means of improving worker efficiency and comfort. The effect of plant waste or by-products on nearby areas must be taken into consideration.

It is estimated that the time lost annually in the United States due to illness and occupational conditions amounts to 400-500 million man days annually.[12] In actuality only a very small percentage of the number of days lost in industry is due to conditions arising out of the work environment. While this percentage is small, the actual number of days lost is considerable and is the most easily reduced by adequate controls.

In order for a case of occupational disease to be produced, there must exist three general requirements (see Fig. 1). First, there must be an uncontrolled source of exposure to chemical, physical, or biological agents. This source must contaminate either air, food, or water, or come into contact with an unprotected individual. Occupational diseases are not communicable except in the case of those of biological origin. The disease is acquired only through exposure to the offending material. Epidemics of occupational disease are the result of the exposure of large groups of unprotected persons to hazardous conditions at the same time. The following sections of this presentation discuss briefly some of the basic principles with regard to the sources of occupational diseases and their means of control from an engineering viewpoint.

Chemical exposures consist of toxic or hazardous gases, mist, dust, fumes, vapors and smokes. Physical hazards in the work environment include abnormalities of temperature, humidity, moisture, shock and vibration, deficiencies of illumination, exposure of radiant energy and ionizing energy and noise. The biological agents of occupational disease include bacteria, fungus, pollens and parasites. Toxic plants such as poison ivy are also included under this category (see Table I). In addition to these, there exists a problem of situational stress and worker fatigue. In addition to procedures to determine whether or not an individual is physically capable of doing a job, consideration must be given to the job itself to insure that its demands do not exceed normal capabilities. Occupational fatigue may be the result of physical environmental factors, psychological factors, job requirements or a combination of all three.[13]



CONDITIONS FOR PRODUCTION OF
OCCUPATIONAL DISEASES

FIG 1

Occupational diseases are not restricted to production line type facilities. Approximately 99% of the working population of the United States are employed in plants, shops or activities employing less than 1,000 workers.[14] The agricultural employed population is exposed to a wide variety of hazards. Even the hobbyist such as the model airplane builder is exposed to dangers. One of the most glaring examples of this type of hazard is afforded by the recommendation by many plastic model kit manufactueres to use carbon tetrachloride as a solvent for bonding the component parts of the model. In a number of these instructions no reference is made to the potential toxicity of the material by skin absorption although warnings such as "Do Not Breathe the Fumes" may be provided. A staggering number of deaths from carbon monoxide poisoning due to faulty heating equipment portrays a need for continuous awareness of the dangers in the everyday living and working environment. The vast majority of large industries have become increasingly aware of the importance of a good preventive and occupational medical program. Unfortunately, in the case of small plants and self-employed persons, this awareness has not been developed nor have official health agencies been able to devote the proper amount of time to this condition. Here again a challenge exists to the entire engineering profession to insure that processes and products developed contain inherent safeguards to the user. An estimate of the extent of some of the chemical exposures in the United States may be seen in Fig. 2.

From the foregoing, it may be seen that there are two distinct aspects of the engineer's activities with regard to occupational health. First, there is the moral and legal responsibility for all engineers to include in basic designs consideration for the health, safety and effective functioning of persons who are either exposed to, or must work with, the product or process or structure involved. In this area of activity and interest the advice and assistance of engineering specialists and applied scientists is essential.

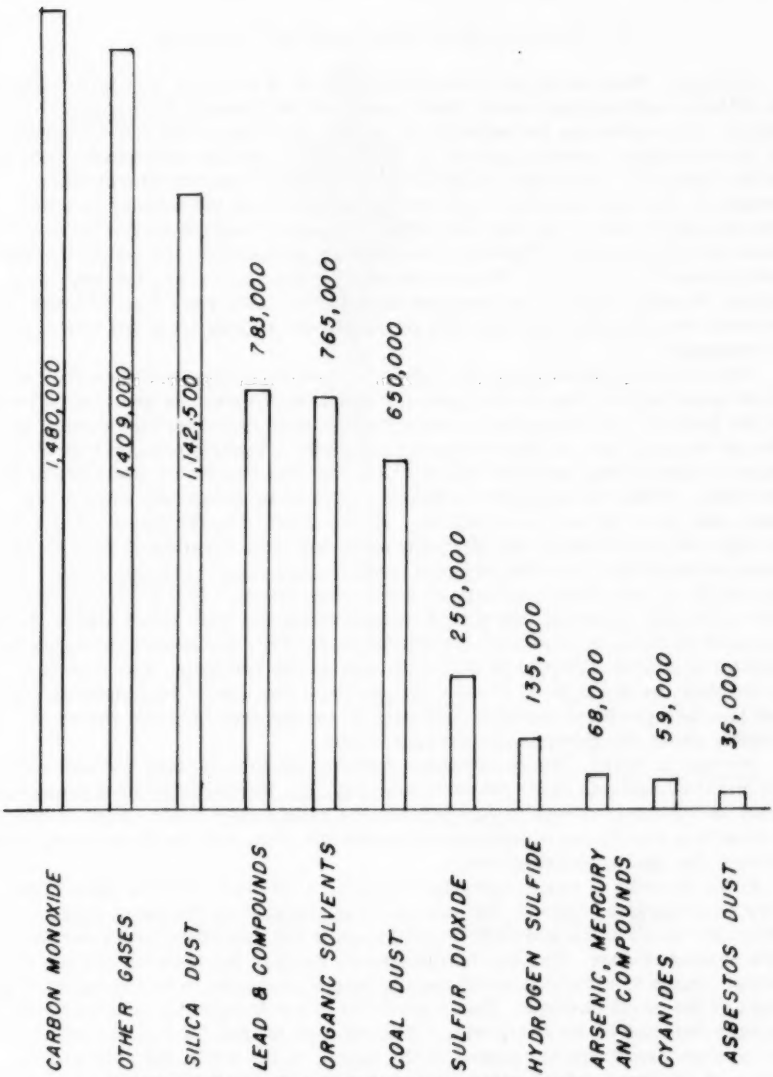
Secondly, the specialized field of sanitary engineering involves the evaluation, detection and control of adverse environmental factors in the occupational environment, the development of means of improving the environment, so that man may better function therein.

TABLE I. — SOURCES OF OCCUPATIONAL DISEASE

1. CHEMICAL HAZARDS
   - Toxic gases, vapors, mists and fumes
   - Irritant gases, vapors, mists and fumes
   - Toxic particulate materials
   - Irritant particulate materials

2. PHYSICAL HAZARDS
   - Abnormalities of temperature and humidity
   - Abnormalities of pressure
   - Defective illumination
   - Noise
   - Repeated motion, shock and vibration
   - Exposure to radiation (ultraviolet, infrared, and ionizing)

3. BIOLOGICAL HAZARDS
   - Infectious diseases
   - Fungi
   - Parasites



NUMBER OF WORKERS EXPOSED TO OCCUPATIONAL HAZARDS

(ADAPTED FROM "ENVIRONMENT AND HEALTH," PHS PUBL # 84)

FIG 2

It includes provision of advice and assistance to engineering colleagues regarding the biotechnological aspects of their activities.

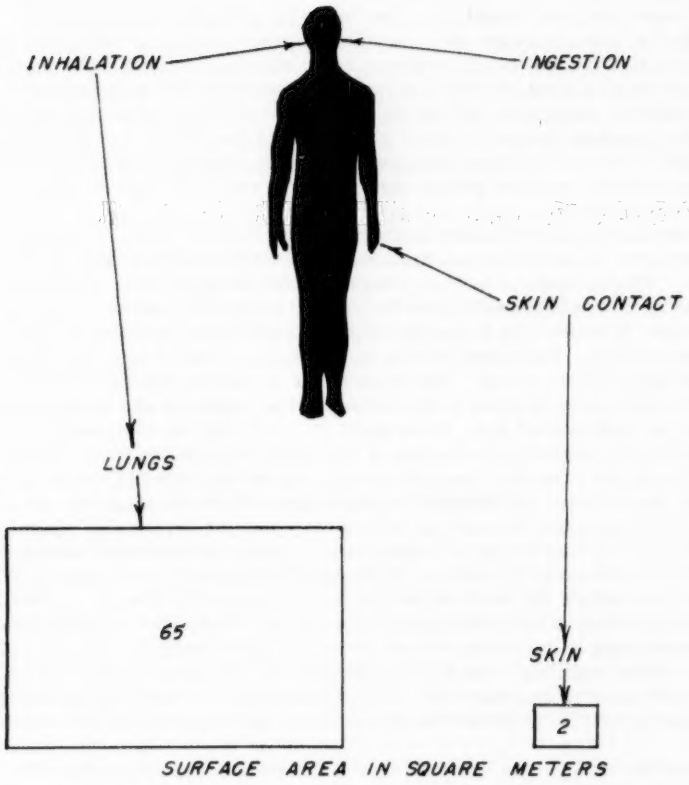
IV. Fundamentals of Physiology and Toxicology

General. Many of the physiological functions of the body may be considered in refined mathematical terms based upon very well understood physical principles. Examples are the behavior of dust in the respiratory tract, operation of the circulatory system and the functions of the various membranes such as in the kidney.[10] According to Baillif and Kimmel,[15] the structures which comprise the body should be understood first and then the manner in which the structures carry out their activity. The main components are the skeletal, muscular, circulatory, digestive, respiratory, urogenital, and endocrine and central nervous systems. Included in the nervous system are the organs of vision, hearing, speech, and sensory perceptions. Any one or all of these systems may be adversely affected by conditions arising from the work environment.

The cause and effect factors of chemical and physical exposures are related quantitatively and depend upon the duration of exposure and concentration of the toxicant. As an example, some toxic vapors may exert their main action as an anesthetic in high concentration while a lower concentration of the same compound may produce injury to the nervous system or some organ of the body. Effects of exposure to either abnormal or dangerous work conditions may be either acute or chronic. Acute effects are the result of exposure to high concentrations of the offending agent for such duration of time as to produce immediate or short delayed positive symptoms. Chronic effects are the result of long-term exposure to concentrations such that no dramatic onset of disease is caused, but a slow change within the body takes place. As an example of an acute exposure, the headache, fatigue, and nausea produced by inhalation of over 400 ppm of carbon monoxide for two hours may be cited. In contrast, an example of chronic occupational disease is the kidney damage and jaundice produced through inhalation of carbon tetrachloride fumes at slightly above the permissible exposure level.

Portals of Entry. There are three primary portals of entry through which chemical compounds enter the body (see Fig. 3). Perhaps the most important from an occupational health viewpoint is the respiratory tract. Next in importance is absorption of materials through the skin, and the third is ingestion through the gastrointestinal tract.

In the process of respiration the air is first forced by atmospheric pressure on inspiration through the nose into the chamber of the nasal cavity, where the nasal hairs and eddy currents cause the deposition of a considerable amount of dust. The air then passes on through the pharynx making an abrupt change in direction which causes larger particles to be impinged on the walls of the nasal pharynx. These particles are subsequently removed either by expectoration or by swallowing. The air then passes through the upper respiratory tract into the alveoli of the lungs. In the adult, the respiratory tissue of the lungs, which acts as an exchange between the blood and the air, presents a surface area of approximately 65 square meters. Such factors as the concentration of the toxicant in the air, solubility in blood tissues, length of exposure, rate of breathing, rate of circulation, and whether the material is reacting with body tissue determines the accumulation of the gas or vapor in the body. Determination of the effect of such accumulation must take into consideration whether any detoxification mechanisms take place, what the



PORTALS OF ENTRY OF TOXIC MATERIALS

FIG 3

ultimate storage site within the body is, and the method and rate of elimination. A vapor relatively insoluble in blood plasma will saturate the body rapidly. On the other hand, if it is very soluble in blood, saturation will be slow. Once the lungs have been filled with vapor (after the first few inhalations) they are equilibrated with the air at an only slightly lesser concentration of vapor than the inhaled air. Due to the fact that the arterial blood supply to the brain is large, and a brief exposure to a high concentration of gas or vapor of low solubility produces rapid effects, this phenomena has an important bearing upon the effect of brief exposures to high concentrations of slightly soluble materials. Moderate concentrations may induce unconsciousness after one-half hour or more of exposure and the effects will be somewhat prolonged, while on the other hand concentrations which are sufficiently high to induce unconsciousness quickly may be recovered from shortly after removal from exposure.

The absorption of particulate matter, such as dust or fumes, involves similar processes of accumulation, distribution and elimination as that in the case of gases. This process is in fact; however, more complicated. Retention of particles is in direct proportion to the rate of respiration below 20 inhalations per minute. It is directly proportional to the size of the particles or their aggregate density. Particles ranging in size from .25 to 16 microns show approximately 50% retention. Particles below .1 micron are generally thought to be too small to be trapped in the alveoli of the lungs and are exhaled much the same as undissolved gas. Some dusts (5 to 20 microns in diameter) are impinged on the respiratory mucosa of the upper respiratory tract. Particles trapped along the bronchial tree are swept towards the pharynx by the ciliary action of the tracheal and bronchial membranes. Particles caught in the alveoli are probably absorbed through the wall or they may be engulfed by phagocytic cells and carried into the blood capillaries or enter the lumhatics where they will be concentrated in the nodes. Particles of silica of 0.1 to 1 micron in diameter are among the most active and most dangerous. Similarly, particles of beryllium afford a most serious hazard. A fact frequently not recognized is that pertaining to materials which are only slightly volatile. Concentrations far above those possible from partial pressure of the gaseous phase at room temperature may be encountered. Vapors which may be harmless at ordinary temperatures may be extremely dangerous when atomized as an aerosol or mist.

The surface area of the average adult male body is approximately two square meters. It will be seen that the skin is an important portal of entry for those materials which may penetrate the intact skin. The absorption of chemicals through open lesions is much more rapid than through the unharmed skin. Most electrolytes in water do not penetrate the skin in significant amounts. Benzene (benzol, not to be confused with benzine), toluene, xylene, and the chlorinated hydrocarbons are absorbed to the degree that harmful effects may be produced. The salts of lead, tin, copper, arsenic, bismuth, antimony and mercury are thought to penetrate by combination with fatty acid radicals of sweat. Dangerous amounts of hydrogen cyanide may be taken into the body through the skin from contaminated air. Materials such as nitrobenzene, dinitrobenzene, nitrotoluene, dinitrotoluene, analine, dimethylanaline, and nitroglycerine are rapidly absorbed through skin contact with these materials or solutions containing them. DDT and many other of the agricultural insecticides may be absorbed through the skin when dissolved in a petroleum base.

The gastrointestinal tract may serve as a portal of entry secondary to inhalation, as described above. The eating of contaminated food or beverage or placing contaminated fingers or other objects in the mouth serves as a means of primary entry into the gastrointestinal tract of intoxicants. While this mode of entry plays a minor role in absorption of most toxic materials, its importance cannot be overlooked. The importance of washing the hands prior to eating or smoking continues to be a primary preventive measure.

Mode of Action and Effects. The mode of action of chemicals on the body may be classified on physiological considerations as outlined by Henderson and Haggard.[16] As shown in Table II, the five main classes are: (1) irritants, (2) asphyxiants, (3) anesthetics and narcotics, (4) systemic poisons, and (5) particulate matter other than systemic poisons.

TABLE II. — MODE OF ACTION OF TOXIC MATERIALS

1. Irritants - Affecting
    a. Upper respiratory tract
    b. Upper respiratory tract and pulmonary tissues
    c. Terminal respiratory tree
    d. Skin
2. Asphyxiants
    a. Simple
    b. Chemical
3. Anesthetic and Narcotics
4. Systemic Poisons
5. Complex Tissue and Organic Responses

Irritant materials may be corrosive or vesicant in nature. The results of contacts with these materials may produce a mild irritation, the production of a vesicle or a blister, or a third degree burn resulting in actual scarring and destruction of the tissue. Concentration is apparently of greater significance than time or duration of exposure.

Irritant materials may be divided into four major groups: (1) Those that affect the upper respiratory tract, (2) those that affect both the upper respiratory tract and pulmonary tissues, (3) those that affect the terminal respiratory tree and alveoli, and (4) those which produce a corrosive or irritant effect upon the skin. One of the most common examples of an irritant affecting the upper respiratory tract is acrolein which results mainly from the combustion of fuels and produces an irritation of the nose and eyes. Also known as allyl aldehyde, it has a disagreeable and active penetrating odor. Petroleum and petroleum products in themselves are toxic substances in varying degree. Exposure to low concentrations for a few minutes will cause an almost immediate irritation to mucous membranes and of the conjunctiva of the eye as well as the upper respiratory tract. Among the irritants which chiefly irritate the upper respiratory tract and pulmonary tissues are bromine, chlorine, chlorine oxides, cyanogen bromide, cyanogen chloride, diethyl- and dimethylsulfate, fluorine, iodine, ozone, sulphur chloride, phosphorous trichloride, and phosphorous pentachloride. The effect of exposure to chlorine which is a typical member of this group is that of bronchitis, dryness of the conjunctiva and occasionally a painful irritation of the cornea. Symptoms such as headaches, vertigo, loss of weight, anemia, or premature senility are the result of chronic exposure to these materials. Arsenic trichloride, nitrogen dioxide, nitrogen tetraoxide, and phosgene are typical materials which affect the terminal respiratory tree and lung. Gasolene is a good example of a primary skin irritant.

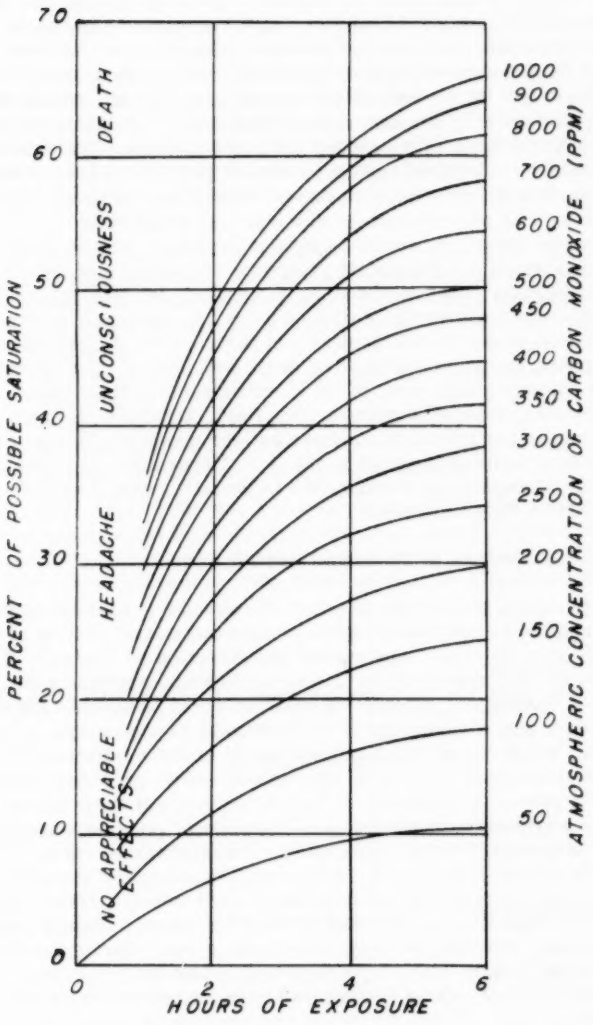
Asphyxiants may be divided into two principle groups - the simple asphyxiants and chemical asphyxiants. Both groups of compounds exert their effects by interfering with the processes of oxidation in the tissues. Carbon dioxide, ethane, helium, hydrogen, methane, nitrogen, and nitrous oxide are examples of simple asphyxiants. They are physiologically inert gases acting primarily by dilution of atmospheric oxygen below the partial pressure required to maintain oxygen saturation of the blood sufficient for normal tissue respiration. Methane and nitrous oxide, while included in example above, may also be considered as belonging to the group of compounds of gaseous hydrocarbons acting as anesthetics. Frequently the toxic effects encountered in exposure to this group are often caused by other impurities normally found in commercially available sources. Commercial ethylene has occasionally been directly contaminated with carbon monoxide. Acetylene used in welding contained 10 to 14% of the impurities, including phosgene, carbon disulphide, hydrogen sulphide, arsenic, carbon monoxide, and other miscellaneous hydrocarbons. Carbon dioxide is a simple asphyxiant. The release of carbon dioxide from automatic or manually operated fire extinguishing equipment in an enclosed space may result in asphyxiation of the occupants thereof through the replacement of the available oxygen supply.

Chemical asphyxiants either prevent the transportation of oxygen from the lung through the blood stream or else interfere with normal oxidation in the tissue even though the blood itself is well oxygenated. Examples of this type of materials are carbon monoxide, cyanide compounds, aniline, and hydrogen sulphide.

One of the most common of this group of materials, affording one of the greatest hazards, is carbon monoxide. The toxicity of this gas is a result of its affinity for hemoglobin, approximately 210 times that of oxygen. The carboxy hemoglobin which is formed does not rapidly take up oxygen, and hence interferes with the ability of the blood to maintain the flow of oxygen from the lungs to the tissue. The results of exposure to varying concentrations of carbon monoxide in the atmosphere are shown in Figure 4. One of the most serious consequences of exposure to low concentrations of carbon monoxide is the dulling of intellect and judgment without awareness of the subject. Reaction times are slowed down and oratory and visual hallucinations may take place without warning.

Perhaps the largest group of chemicals used in homes and in industry is halogenated hydrocarbons. For the most part, these materials exert an anesthetic and narcotic effect. Common chloroform (trichloromethane) is a representative member of this family of chemicals. Carbon tetrachloride is widely used without awareness of the dangers presented by this material. The toxic reactions which follow single exposures to high concentrations or chronic results or prolonged exposure to moderate concentrations are primarily limited to effects upon the kidneys and the liver. Initial acute intoxication is centered around the central nervous system. Early symptoms of exposure to these materials are dizziness, headaches, stupor, nausea and vomiting.

The systemic poisons include those materials which cause organic injury to one or more of the visceral organs, the blood and blood-forming system, and the nervous system. This group also includes the toxic metals. Halogenated hydrocarbons belong to the first group. Compounds such as benzene, phenols, and, to a certain degree, toluene, xylene, naphthalene are toxic due to their effects upon the blood and blood-forming organs. The nerve poisons include carbon disulphide, methyl alcohol, thiophene, and some of the newer insecticides such as parathion. Toxic metals include lead, mercury, cadmium,



EFFECTS OF EXPOSURE TO CARBON MONOXIDE

FIG 4

antimony, manganese, and others. Extent of the absorption of these metals varies with the solubility and chemical reactivity of the compound, the number of particles distributed in the atmosphere, and the duration of exposure. Particulate matter other than the systemic poisons includes dusts, irritants, bacteria and fungi. Silica, asbestos and beryllium are among the principal causes of fibrosis of the lungs. Dusty operations such as grinding and buffing of resins and certain plastics may produce allergic reactions. Similarly, pollen dust and other organic dusts may produce serious problems. Toxic dusts include acids, alkaloids, fluorides, and chromates in particulate form. These substances frequently act only when dissolved, principally by perspiration or moisture on the skin or when in contact with mucous membranes.

Exposure (either chronic or acute) to physical agents produces tissue or organic responses which are frequently complex. The exact mechanism of these responses in many cases is obscure. In general, cell damage or destruction accompanied by systemic reaction occurs. As an example, exposure to ionizing radiation produces cell damage and destruction. If the exposure is sufficiently great, radiation sickness or death will follow. The effects of exposure to the various components of the electromagnetic spectrum should be understood by all personnel working in this field. Detailed information relative to exposures in various occupations and the symptoms of onset of occupational disease are summarized in the U. S. Department of Labor Bulletin No. 41, 1942, "Occupational Hazards and Diagnostic Signs," available from the U. S. Government Printing Office.

V. Concept of Threshold Limit Values

As pointed out above, the degree of effect of exposure to hazards in the environment are related to the concentration of the contaminant, the duration of exposure thereto and the rate of absorption and excretion by the body. The establishment of control measures for airborne chemical contaminants and in fact the design of ventilation systems for areas in which chemicals are utilized must be predicated upon a knowledge of the maximum concentration of airborne chemicals, which can be tolerated without ill health or discomfort. The contamination of workroom air may be determined rather precisely under the normal laws of physics. A knowledge of the threshold limit value allows the determination of required ventilation rates. The term "maximum allowable concentration" is gradually being replaced by "threshold limit value."[17] The Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists compiles extensive lists of such values. These values represent the amount of gas, vapor, fume or dust for which continued exposure for eight hours a day, five days a week, fifty weeks a year, during a normal working life of 30-40 years, will not produce bodily discomfort or impairment of function. Many of these values are derived from extrapolation of experiments on animals to man. All of the values are continually subject to revision as more toxicological data becomes available.

It should be emphasized that there is a wide range in the individual response to various chemical exposures. It is obvious that if the maximum allowable concentration for a particular material is 50 ppm, exposure to 55 or 60 ppm for a short period of time is not going to have a deleterious effect. The threshold limit values should be utilized as guides to assist in defining more or less safe working conditions.[18] The same philosophy as is utilized in the development of threshold limit values for chemical exposures also applies in general to the permissible exposure for such hazards as ionizing radiation,

noise, abnormalities of temperature and humidity, deficiencies of illumination, and shock and vibration.

In the development of permissible exposure limits (MAC's or threshold limit values) it is essential that the toxicity of the chemicals concerned be known. Toxicity is related to lethal values to man. It has been proposed that the toxicity rating be related to commonly understood terms. As an example, an extremely toxic compound would be one of which one grain would probably be lethal to man. A relatively harmless material would be one which would require a quart or more to produce death. The range of toxicity is shown in Figure 5. Another classification of physiological responses, according to Patty[13], is as follows:

"a. Amount producing detectable or other degree of odor.
b. Amount producing detectable or other degree of irritation.
c. Maximum amount for repeated daily 8-hour exposure without injury.
d. Maximum amount for a single 8-hour exposure without serious disturbance.
e. Maximum amount for a single one-hour exposure without serious disturbance.
f. Amount dangerous to life within 4-8 hours.
g. Amount dangerous to life within one-half to one hour.
h. Amount causing death within a few minutes."

The Manufacturing Chemists' Association has developed a classification for chemical hazards and the degrees of effect as shown in Table III.[19] This Association has prepared a Handbook of Warning Labels for all categories of hazardous chemicals which gives excellent data on a wide number of commonly used chemicals.

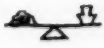
Toxicity Rating	Description	Probable Lethal Dose for Man	
1	Extremely Toxic	•	1 grain
2	Highly Toxic		1 teaspoon (4 cc.)
3	Moderately Toxic		1 ounce
4	Slightly Toxic		1 pint
5	Practically Non-Toxic		1 quart
6	Relatively Harmless		1 quart

Fig. 5

Toxicity Classification Ranges

TABLE III

MANUFACTURING CHEMISTS' ASSOCIATION
CLASSIFICATION OF CHEMICAL HAZARDS AND DEGREES OF EFFECT

Hazard Classification		Degrees of Hazard and Effects
I	Materials giving vapors rapidly toxic or extremely irritating on exposure for a short time or to low concentrations.	Vapor (extremely) hazardous (irritating) hazardous liquid and vapor (gas under pressure) vapor poisonous if inhaled, vapor may be fatal if inhaled.
II	Materials giving vapors hazardous from prolonged or repeated exposures or exposure to high concentrations.	Vapor harmful. Causes irritation to eyes, nose and throat.
III	Gases and vapors physiologically inert.	Gas (vapor) reduces oxygen available for breathing. Releases heavy gas (vapor) which may cause suffocation.
IV	Materials in dust form hazardous from inhalation or contact.	Hazardous (harmful) dust. Harmful if inhaled. Causes irritation of skin, nose, and throat.
V	Skin irritants - corrosive	Causes severe burns. Causes burns. May cause burns.
VI	Materials causing skin irritation after prolonged or repeated contact.	Causes skin irritation. May cause skin irritation.
VII	Materials toxic through skin absorption.	Hazardous solid (liquid). Rapidly absorbed through skin. Absorbed through skin.
VIII	Materials toxic if swallowed.	Poisonous if swallowed. May be fatal if swallowed. Harmful if swallowed.

VI. Concepts of Engineering Application

As shown in Figure 6, the basic procedure involved in the control of an occupational health hazard is the substitution of a less toxic or dangerous component or procedure for one constituting an innocuous component. When this is impossible, the second step in the engineering control of occupational health hazards is to design protective devices. Under some circumstances, even properly designed processes still constitute a hazard or the nature of the work involved precludes the development of integral safeguards. Under these conditions, personal protective devices must be utilized. Where economy dictates or the nature of the work is such as to present special hazards, a combination of the three basic procedures must be applied. This principle of multiple barriers is utilized when dealing with extremely toxic processes. Regardless of whether one is dealing with the correction of existing hazards, the design of new work procedures or equipment or the development of products, the same general procedures outlined above should be followed.

It is obvious that it is cheaper in the long run to eliminate the requirement for costly protective or control measures through the substitution of a less dangerous or less offending material. In the case of chemical or physical hazards in the environment, consideration must be given not only to the work process dangers but also to the control of waste products and attendant atmospheric or stream pollution hazards. In the following discussion, chemical hazards are generally utilized as examples as they are among the more common problems found throughout all occupations. The same principles apply to the control of physical hazards and to job or human engineering procedures. Frequently the very condition which creates the hazard is what makes the particular process or material useful as in the case of ionizing radiation. Under these conditions, elimination or substitution of less toxic or dangerous materials is impossible, and protective measures must be provided.

An example of substitution of a less toxic or dangerous material for a hazardous one is the use of trichloroethylene instead of carbon tetrachloride as a cleaning solvent. The toxicity of trichloroethylene is approximately one-half that of carbon tetrachloride. In addition, the material is much less readily absorbed through the skin. Although it is less toxic than carbon tetrachloride, appropriate ventilation methods must be utilized to protect personnel against the effects of inhalation of excessive concentrations of this vapor. Another example of substitution of a product is the cause of the use of freon as a refrigerant in place of methyl chloride in household refrigerators. A well known example of elimination of a hazard is the use of non-silica bearing sands for sandblast operations as a means of controlling silicosis.

As pointed out above, even the substitution of a less toxic material for one which affords a danger does not always eliminate completely the hazards, as the substitute may be of such a nature as to require controls. Where hazardous materials must be utilized, the process should be designed so as to afford the least possible exposure of personnel to the offending materials. Consideration should be first given to isolating the process in a remote area if the danger warrants it. Where isolation is impossible, complete inclosure or utilization of closed systems should be resorted to. If the material is of sufficient danger, remote handling equipment with servo mechanisms and television viewing may be required, as in the case of handling very high levels of radioactivity. An entire field of remote control engineering has been developed to deal with this problem.[20]

ENGINEERING CONTROL PRINCIPLES

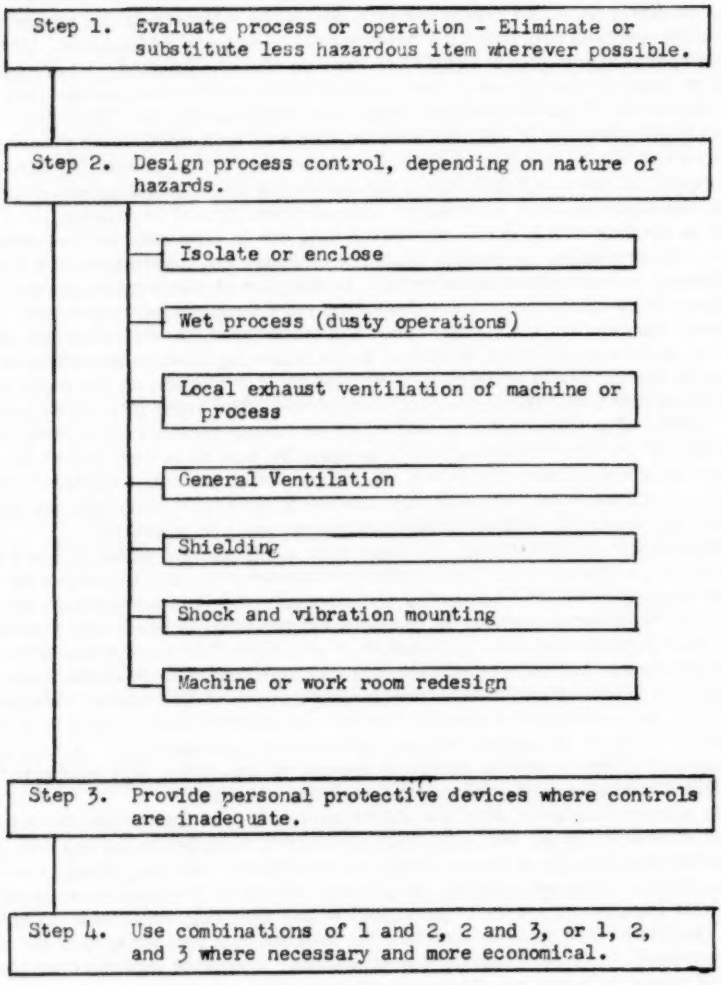

Step 1. Evaluate process or operation - Eliminate or substitute less hazardous item wherever possible.
Step 2. Design process control, depending on nature of hazards.
Isolate or enclose
Wet process (dusty operations)
Local exhaust ventilation of machine or process
General Ventilation
Shielding
Shock and vibration mounting
Machine or work room redesign
Step 3. Provide personal protective devices where controls are inadequate.
Step 4. Use combinations of 1 and 2, 2 and 3, or 1, 2, and 3 where necessary and more economical.

Fig. 6

In dealing with materials in which the operation involves the creation of a dust hazard such as in grinding and buffing of lead or other metals, use of a wet process will materially reduce or eliminate the hazard. Another example of this type of control is the scraping of radium painted instrument dials under oil or solvent so as to prevent the contamination of room air with radioactive dust. In dealing with toxic gas vapors or other atmospheric contaminants, local exhaust ventilation is frequently required. Local exhaust ventilation is also useful in the control of dust hazards. Occasionally circumstances are such that general ventilation of the workroom atmosphere is all that is required. A good example of a typical local exhaust system is that found in any well equipped garage in which carbon monoxide from the exhaust is conducted to the outside of the building by a collector system connected to the exhaust pipes. One of the most up-to-date sources of information relative to the design of exhaust ventilation systems for the control of industrial contaminants is the American Conference of Governmental Industrial Hygienists' Handbook on Industrial Ventilation. Design of local exhaust ventilation systems must be such as to draw the contaminant away from the breathing zone of the operator. Proper consideration must be given to the possibilities of the exhausted material becoming a source of air pollution, either to the plant or the nearby community.

In the case of exposure to physical hazards many of the control measures involved require the application of basic scientific principles. In the case of shock and vibration, proper isolation or absorption devices may be required. The control of impact noise from machine tools by the mounting of the tools on felt pads is a type of control of this nature. The principle of reflection of radiant heat by aluminum sheeting is a useful means of protection of workers against the harmful effects of this exposure.

Personal protective devices include such equipment as respirators, gloves, gauntlets, aprons, impermeable suits, and similar materials. Since protective equipment is only as good as the use to which the wearer puts it, this type of control measure is the least desirable. Great care must be exercised in the selection of respirators and gas masks to insure that they are suitable for the particular exposure involved. Protective creams are useful for certain types of exposure but have inherent disadvantages under some conditions. Oil soluble creams are of little value if the chemical exposure involves an oil base chemical. Similarly, water soluble creams afford no protection against aqueous solution hazards. Safety glasses and safety shoes are other types of personal protective devices. One of the most difficult problems with regard to the utilization of personal protective equipment is that of user acceptance. Unfortunately, many of the protective devices are uncomfortable to wear, and workers will not utilize them in spite of the fact that their health may be impaired. In certain operations (such as gasolene fuel tank cleaning) failure to utilize proper protective equipment may result in loss of life of workers. The main burden of responsibility in the proper use of individual protective equipment lies with job supervisors.

It was pointed out above that it is possible to derive specifications for human performance against job stresses, and based upon these specifications to develop adequate control measures. Utilizing an idea employed by McFarland,[21] a method has been developed which is applicable not only to specific job hazard control measure design but also to hazards evaluation of existing processes or operations. In addition, this technique may be applied to any engineering works or design to insure that recognition is given to the human factors involved.

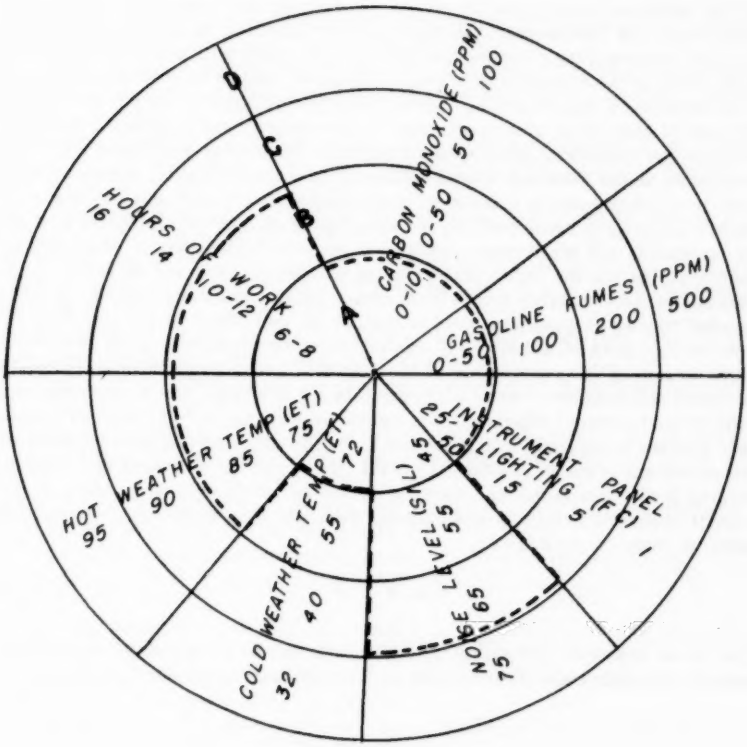
In using this method, a pie diagram is drawn with concentric circles showing varying degrees of environmental conditions beginning with "comfort," through "acceptable" to "uncomfortable" to "hazardous". The importance of environmental aspects of the condition under consideration are shown as sectors of the overall circle, sized according to the degree of effect upon the total operation. From a knowledge of the various environmental factors, the parameters for the various environmental criteria can then be shown on the chart. A pictorial presentation of the environmental factors is thus created. Requirements for design to take into account human factors are easily visualized. The same procedure may be utilized in evaluating existing conditions by plotting on the chart the observed conditions. An example of this type of approach to human engineering problems is shown in Figure 7. An occupational environmental specification for a truck driver is shown as an example of the factors to which consideration would be given in the design of a motor vehicle with regard to driver health, comfort, and safety of operation. One of the major causes of human failure is not subject to engineering correction but is related to good personnel management, namely, hours of work.

In determining the control measures and design factors of the vehicle cab and the vehicle itself, it was decided a 10 to 12 hour maximum trip might be required. This was within the acceptable limits. A 10 ppm carbon monoxide concentration (maximum) would require a carefully designed vehicle exhaust system and proper cab ventilation. In order to provide comfort in hot weather, it is essential that the cab be ventilated and that there be adequate insulation between the engine compartment and the cab. For winter operations, it is obvious that the cab must be protected against drafts and an adequate heater be installed. The instrument panel lighting not only requires consideration of the provision of proper illumination but also the protection against glare in excessive contrast. This involves the design of the windshield and painting of the instrument panel. Control of noise requires soundproofing of the engine and design of the cab to preclude transmission of mechanical vibration and noises from the drive shaft and tires and other mechanical components. Proper design of fuel handling components and cab ventilation is necessary for protection against gasolene fumes. Protection against carbon monoside requires study of location of the exhaust with regard to possible leaks and direction of air flow to cab.

The development of such graphic occupational environmental specifications requires a thorough understanding of the overall factors involved in man's adjustment to his environment. In the evaluation of occupational conditions, it is essential that there be an integration of medical and engineering techniques. Regardless of the safeguards provided in any particular work area, possibility always exists that careless individuals will disregard the barriers provided for their safety and thus be exposed to conditions detrimental to their health.

In evaluating work conditions, a wide variety of instrumentation is available to the skilled sanitary or industrial hygiene engineer. Intelligent use of this equipment requires an understanding of its limitations and capabilities. In addition, sampling techniques must take into consideration the exposure potentialities of the particular job under consideration. Readings must always be taken in the area in which the worker is actually exposed. It is meaningless, for example, to take atmospheric samples in any area other than that which the breathing zone of the worker occupies during the work operation. The joint efforts of physicians and engineers trained in the principles of occupational medicine and industrial health are essential to the proper evaluation of alleged

A COMFORTABLE
B ACCEPTABLE
C UNCOMFORTABLE
D HAZARDOUS



EXAMPLE OF AN OCCUPATIONAL ENVIRONMENTAL HEALTH SPECIFICATION

FIG 7

cases of occupational illness. Results of environmental investigations should be an integral part of any case history dealing with an occupational disease.

VII. Concepts of Training

All engineers should receive at least one semester of "engineering physiology." The purpose of this course should be to acquaint the individual with various physiological processes of the body, its capabilities and limitations, and its anthropological specifications. A glaring need exists for more emphasis upon the fundamentals of elementary statistics in engineering education. While all engineering courses include a large number of hours in laboratory work, little or no attention is given to the basic theory of statistical evaluation of the results of observations. Since human performance varies according to the laws of statistics, this knowledge is even more essential in the field of sanitary and industrial hygiene engineering. There has developed a growing awareness of the need for specialization (regardless of basic engineering degree) in the engineering control of environmental occupational factors. While notable steps have been made in the developing of special curricula in a number of educational institutions, much yet remains to be done to provide adequate training for the individual desiring to specialize in the broad field of engineering as it relates to environmental and occupational health. A well-rounded course at graduate level to qualify an individual in the broadest aspects of this area of activity will probably require a minimum of two years. There is a need for realization of the fact that regardless of undergraduate specialty, all engineers have training in basic sciences, basic engineering subjects and general educational material as well as the specialized phases of their particular branch of engineering. To the detailed engineering specialization as normally given at graduate level, there should be added the required training in the biological and medical sciences which will equip the specialist in environmental health to successfully function as a member of the physician-engineer team of the future.

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